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DEVELOPMENT OF A STUDY PLAN FOR DEFINITION OF FCBS USAGE, WASTES, AND POTENTIAL SUBSTITUTION IN THE INVESTMENT CASTING INDUSTRY: TASK III

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TASK III

JANUARY 1976

FINAL REPORT

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF TOXIC SUBSTANCES
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A study plan, designed to define the usage of polychlorinated biphenyls (PCBs) and terphenyls (PCTs) in the investment casting industry, was developed under the subject task. Current knowledge was reviewed and used as input to the study plan development. Methods of information gathering and data sources, as required to define industry scope and technology, wastes, and substitution technology, were also determined.

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Task III

EPA Contract No. 68-01-3259

EPA Project Officer: Thomas Kopp

For

Environmental Protection Agency

Office of Toxic Substances
4th and M Streets, S.W.
Washington, D.C. 20460

January 1976

REVIEW NOTICE

This report has been reviewed by the Office of Toxic Substances, EPA and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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1.0 SUMMARY

This report summarizes the current knowledge of decachlorobiphenyl (deka) and polychlorinated terphenyls (PCTs) as wax fillers in the investment casting industry; this knowledge is used to develop a detailed study plan of the industry. Significant information gathering efforts would be required to establish a complete picture of the practices, processes, and products of this industry, which, in this instance, is taken to include casting wax manufacture as well as wax usage in foundries. Definition of the waste streams and emissions from the processes used will require sampling and analysis efforts in addition to the gathering of available process data from the industry.

An approach to determining the most suitable alternatives to decachlorobiphenyl and PCTs is presented; filler substitutes and the use of unfilled waxes are the two general alternatives to be studied. At present there appear to be no technical barriers to discontinuation of deka and PCTs as fillers, although use of alternatives may increase product cost on the order of 10 percent. In determining the most promising alternatives, product and process oriented technical factors must be evaluated, but potential environmental and human health effects may prove to be the most important factors in selection. An approach to comparison of alternatives based on technical factors and toxicology data is presented. However, it is anticipated that toxicological data on most alternatives, and also on the currently used materials, will be sparse.

The success of information gathering and in-plant sampling efforts is expected to depend heavily on use of Section 308 (FWPCA) authority. Air emission sampling would be very important to the establishment of an overall process material balance and definition of process losses to the environment.

2.0 INTRODUCTION

2.1 Purpose and Objectives of Task III

Task III under Contract No. 68-01-3259 was initiated December 15, 1975. The purpose of this task was to develop a plan for:

(1) Detailed evaluation of the investment casting industry (wax manufacture and use in casting), including a program to determine the levels of wastes and emissions containing polychlorinated biphenyls (PCBs) and polychlorinated terphenyls (PCTs) and waste disposal practices; and

(2) Evaluate potential substitutes for PCBs and PCTs in the above industries with regard to technical suitability, economics, human health hazard, and environmental acceptability.

The objectives of such a plan would necessarily include the following:

(1) Verification of the magnitude of PCB and PCT wax filler production and use;

(2) Development of detailed process descriptions, including waste streams, leading to a complete mass balance for the production and use processes (including significant variations);

(3) Definition of quantities and concentrations of waste streams, including waste form, abatement techniques, and ultimate disposal methods; and

(4) Evaluation of all reasonable alternatives to the use of PCBs or PCTs in casting.

2.2 Summary of Work to Date on Investment Casting Under Task I of Contract No. 68-01-3259

Task I of the subject contract involves a detailed microeconomic and technical study of regulatory alternatives for PCBs. This task has, of course, included study of the use and substitution potential of decachlorobiphenyl (the only type of PCB intentionally used in investment casting). A brief summary of this work is presented below.

Decachlorobiphenyl ("deka") is used as a pattern wax filler in investment casting. About 400,000 lbs. are imported from Italy (Caffaro) annually by a single wax manufacturer;[1] and about 1,200,000 lbs/year of wax containing deka is produced (unit price about $0.70/lb; yearly sales approximately 0.8 to 1.0 million dollars). Details of the production process are not known. The manufacturer of the deka wax also produces other pattern waxes which presumably contain chlorinated terphenyls (PCTs) as fillers.

In summary, the investment casting process, which is described more thoroughly in Section 3.3, is a lost-wax casting process in which the shape to be cast is molded from wax and then invested or surrounded by a slurry of refractory ceramic. After the ceramic mold has hardened to an appropriate strength, the wax pattern is melted or burned out leaving a molded cavity. Molten metal is then poured into the cavity, and cooled to form the casting.

Some pattern waxes, especially those used in the casting of metal parts requiring tight dimensional tolerances, contain decachlorobiphenyl as the wax filler. Such waxes contain approximately 30 percent (perhaps up to 40 percent) decachlorobiphenyl. It is also known that pattern waxes are recovered and reused several times to form the sprues and gates of the patterns. Wax is apparently used an average of 2.5 times. During the dewaxing process the virgin wax (used to form the pattern) and the old wax (used to form the gates and sprues) are collected as one mixture. Little of the wax is destroyed in the process; therefore, it is considered probable that the investment casting foundries store or dispose of relatively large amounts of used PCB-containing wax.

The major losses of the virgin and used waxes occur during the dewaxing of the ceramic mold. As the ceramic mold is heated to remove the wax, a small portion of the wax diffuses into pores of the mold. Later, the mold with the trapped wax is fired in a furnace to set the mold and remove the wax. Depending on furnace conditions, the decachlorobiphenyl in the wax may be burned or released to the atmosphere. At least several percent of that used is believed to be emitted via this route.

Potentially acceptable process alternatives for the deka PCBs could utilize either a replacement filler material or an unfilled wax. Properties required for a filler are: high melting point (over 300°C), high thermal conductivity, low coefficient of thermal expansion, and minimum ("zero") ash. Isophthalic acid is a promising filler candidate that has been used to a limited extent, but the grade used left an ash residue. A new grade of isophthalic acid, only recently commercialized, exhibits much lower ash and metal contents. This grade costs about $0.35/lb, which is comparable to the deka cost of about $0.30/lb.

Prior to the use of PCBs or PCTs as fillers, unfilled waxes were used. Industry claims that reverting to the use of unfilled waxes would increase production costs by about 10 percent. However, new types of unfilled waxes have recently entered the market, and it is claimed that their properties are equivalent to the filled wax and their cost is slightly lower ($0.60 to $0.65/lb). Although the exact formulation of these waxes is proprietary, they reportedly contain no chlorinated additives.

In summary, technically adequate substitutes appear to be available for decachlorobiphenyl filler in pattern waxes. Maximum increases in costs would be about 10 percent. The only producer of wax containing PCBs could probably change to other types with very little technical difficulty or economic impact.

2.3 Use of Polychlorinated Terphenyls in Investment Casting

Several wax manufacturers use imported PCTs as pattern wax fillers,

but the amounts are not known. Since the general properties of the deka and the PCTs are similar, it is anticipated that the wax production and use processes are similar also. However, this point needs clarification.

Contacts with industry indicate that the volume of PCTs used in wax is probably about the same as that of deka PCBs. Monsanto was the leading, and probably only, U. S. producer of PCTs prior to their voluntary cessation of production in 1972. Domestic production of PCTs by Monsanto through 1972 was as follows:[2]

Year	Millions of Pounds Aroclor 5460
1968	8.87
1969	11.60
1970	17.77
1971	20.21
1972	8.13

It is believed that a relatively small fraction of this production was used in casting waxes, probably on the order of a million or so pounds per year. Aroclor 5460 (Monsanto's trade name for their 60-percent-chlorine PCTs) was used primarily in adhesives, lubricants, and paper coatings.

The current source is Prodelec (France), which markets the material as Electrophenyl T-60 (60 percent chlorine), which, it should also be noted, may contain PCB contaminants.

3.0 CURRENT KNOWLEDGE OF THE INVESTMENT CASTING INDUSTRY

3.1 General Background

There are currently 135 investment casting (IC) foundries and five investment casting wax manufacturing plants in the United States. The IC industry had its start in the United States during World War II when urgent demands for arms and aircraft parts required more efficient methods of producing finished, precision parts than standard machining techniques offered.

During the war the waxes used by IC foundries consisted of a blend of carnauba wax, beeswax, paraffin, and rosins. However, over the last decade wax formulations have evolved which consist of a variety of polymeric compounds and other fillers such as decachlorobiphenyl and PCTs. By reducing the wax content through low-shrinkage fillers (such as PCBs and PCTs) volumetric shrinkage of the ceramic mold is controlled. This allows the production of metal castings with smaller dimensional tolerances than were available with the original unfilled waxes.

Of the 135 foundries, approximately 25 use PCB filled waxes. It is not known how many foundries use PCT blended waxes. Since there are four wax manufacturers which supply the PCT blended waxes and only one which supplies the PCB waxes, it is suspected that the amount of PCT wax blends sold to IC foundries is at least comparable to and perhaps larger than the amount of PCB wax blends sold. The five known wax manufacturing companies are:

1. Yates Manufacturing Company, Inc.
2. M. Argueso and Company, Inc.
3. Freeman Manufacturing Company
4. J. F. McCoughlin Company
5. Pentcraft Tool and Mold Inc.

The Yates Manufacturing Company, Chicago, Ill., is the sole supplier of PCB blended waxes. The PCB compound in their wax products is decachlorobiphenyl which makes up approximately 30 percent of the total wax by weight.(1) Yates currently imports dekа from Caffaro S.P.A., Italy, at a rate of 300,000

to 500,000 lbs. per year, which corresponds to the manufacture of between 1 and 1.5 million pounds of deka wax per year. At a cost of $0.70 per pound,[2] the annual volume of sales of deka wax should be in the range of $700,000 to $1 million per year.

Authorities in Wisconsin are currently studying the investment casting industry in that state; they have obtained and analyzed samples of water effluent that is usually disposed of through municipal sewage systems. Versar communications with the personnel involved indicate their data will not be of major importance to the proposed study plan, although the data on effluent PCB concentrations and the scope of the industry in Wisconsin will, of course, be useful.

3.2 Principles of Investment Casting

The principles of investment casting are the same for both the solid mold and shell processes, but the method of forming the ceramic mold differs somewhat between the two. Both require a pattern, gating to a central sprue, removal of the pattern by melting, pouring metal into the cavity left by the melted pattern, removal of mold material from the cast cluster, and cutting of castings from the sprue.

The investment shell process is depicted in Figure 1.

The Pattern

The process begins with production of a one piece heat-disposable pattern. This pattern is usually made by injecting wax or plastic into a metal die. Dies range from simple, hand-operated single-cavity tools to fully automated multi-cavity devices, depending on production quantities and complexity of the parts to be cast.

A heat-disposable pattern is required for each unit being cast. Each pattern has the exact geometry of the required finished part, but they are made slightly larger in order to compensate for volumetric shrinkage during the pattern production stage and during solidification of the metal

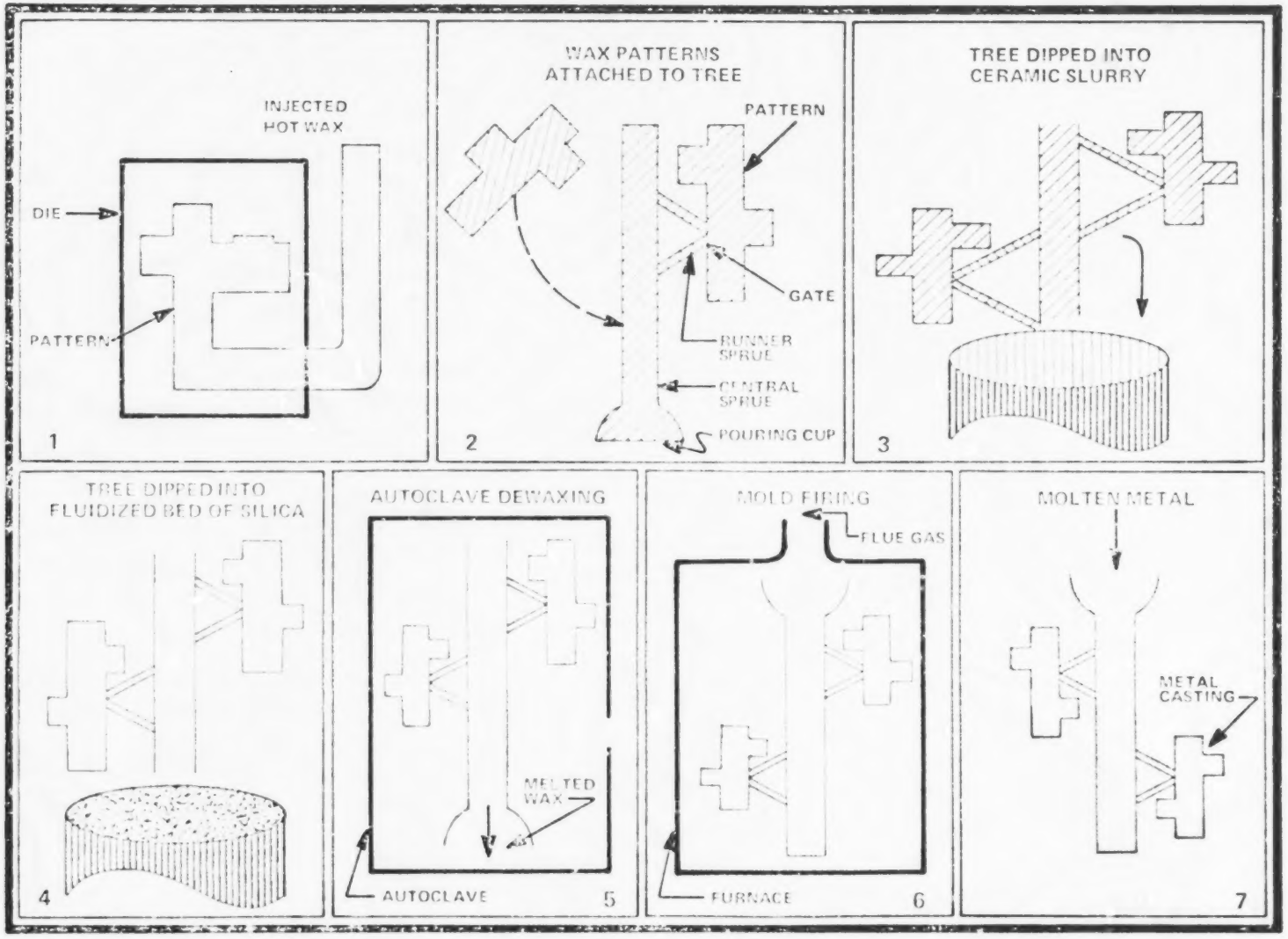

Figure 1. INVESTMENT SHELL PROCESS

in the mold.

The pattern carries one or more gates which are usually located at the heaviest casting section. The gate has three functions:

(1) To attach patterns to the centrally-located sprue or runner, thus forming a tree-shaped cluster;

(2) To provide a passage for the draining of pattern wax once the mold is sufficiently hardened and has been heated; and

(3) To guide molten metal entering the mold cavity in the pouring operation.

Clustering

Patterns are fastened by the gate to one or more runners. The runners are attached to a pouring cup. All of these parts are usually made of wax. Patterns, runners and pouring cup comprise the cluster or tree upon which the ceramic mold is formed. The number of runners and their arrangement on the pouring cup may vary considerably, depending on alloy type and the size and configuration of the casting.

Molding

Up to the point of forming the ceramic mold, all foundries operate in essentially the same manner. After assembling the pattern to a tree, however, they may form the mold by either the investment flask process or the investment shall process.

Solid Mold or Investment Flask Process

There are two investment flask techniques, depending on the type of alloy to be poured. Ferrous alloys require highly refractory materials and binders. The entire cluster is dipped into a ceramic slurry, drained and stuccoed with fine ceramic sand. This step is usually repeated after the first coating has dried. This coated cluster is then placed in an open-end metal can (the flask) which is filled with a coarse slurry of ceramic backup material (investment). The investment hardens to comprise a green mold. When the flask

and its contents are placed into an autoclave, the whole cluster (consisting of wax patterns, runners and sprues) melts and runs out through the pouring cup. The resulting monolithic mold contains cavities of the desired casting shape, with passages leading to them

Nonferrous alloys are cast in ceramic molds bonded with plaster of paris. The entire tree (heat-disposable patterns, gates, runners, and pouring cup) is placed in an open-end metal flask without a first ceramic coating. Investment slurry is poured into the flask, completely surrounding the cluster. Before the binder sets up, the flask is placed under vacuum to remove all air entrapped during mixing of the investment. When the investment becomes hard, patterns are melted out exactly as in ferrous casting.

The Investment Shell Process

This technique, as described in Figure 1, involves dipping the entire cluster into a ceramic slurry, draining it, then coating it with fine ceramic sand. After drying, the process is repeated several times, using progressively coarser grades of ceramic material, until a self-supporting shell has been formed. The thickness of the shell is usually between 3/16 and 5/8 inch.

The coated cluster is then placed in a steam autoclave where the wax melts and runs out through the gates, runners, and pouring cup. The resulting ceramic shell contains cavities of the desired casting shape, with passages leading to them.

Casting

Monolithic shell molds and solid molds must be fired to burn out the last traces of pattern material and to attain a degree of permeability before the molds can be filled with metal. In the case of solid molds, this heating has to proceed slowly, in a controlled cycle which stretches over 12 to 18 hours, to avoid cracking of the mold. The shell molds, made of ceramic material with an extremely low coefficient of expansion, can be placed immediately into a hot furnace. Because the shell molds have relatively

thin walls, they can be fired and ready to pour after only a few hours in the furnaces.

The hot molds may rely on gravity alone to carry the molten metal into the intricacies of the mold, as is common in sand casting, or the process may use vacuum, pressure and/or centrifugal force in order to faithfully reproduce intricate details of the wax patterns.

Melting equipment employed depends on the alloy. For nonferrous alloys, gas fired or electric crucible furnaces are usually used. For ferrous alloys, high frequency induction furnaces and indirect arc furnaces are common.

Cleaning

After cooling, mold materials are removed from the casting cluster with vibrating equipment. Individual castings are usually removed from the cluster by means of cut-off wheels, and any remaining protrusions left by gates or runners are removed by belt-grinding. Generally, castings are sand blasted for smooth finish, then they are ready for such secondary operations as heat treating, straightening and machining.

Reclaiming of Pattern Waxes

The present cost of virgin pattern wax is approximately $.70/lb. In the future, it may be more economical to reclaim wax for use as pattern waxes, in addition to its present use in gates and runners. Furthermore, through a precipitation method, it is possible to remove fillers, including PCBs, from used wax in order to prepare unfilled wax.

Improvement of Investment Casting Processes

Several improvements in the investment casting techniques and procedures have been suggested by TRW Metals in Minerva, Ohio, which developed them through a two-year Air Force contract.[3] The areas of improvement were in wax pattern formation, mold production processes and metal pouring.

Wax pattern formation techniques were improved through simultaneous multiple injections of the gates and runners. The usual procedure requires separate steps.

Two suggestions for improvements were made for the mold production process: (1) elimination of the drying cycle between slurry dipping and sand coating, and (2) the use of microwave ovens to melt pattern wax out of the ceramic mold or shell.

The use of microwave dewaxers would have the advantage of reducing wax emissions in flue gas and drain condensates of autoclave ovens. However, microwave dewaxing may not eliminate wax losses occurring during mold firing as a result of wax trapped in the pores and cavities of the ceramic mold.

3.3 Foundry Process - Use of PCT and PCB Filled Waxes

A flow chart which typifies the use of PCBs in investment casting is presented in Figure 2. PCB filled waxes are purchased from wax manufacturers in bulk quantities of 10,000 or more pounds, sealed in plastic bags and contained in boxes for shipment. The received pattern wax is stored in a stockroom at the foundry until melted for the production of wax patterns. Once melted, the wax is injected into a pattern die where the wax is allowed to solidify. The pattern die is then disassembled and the wax pattern removed. Several wax patterns are produced before forming the tree. The formation of the tree entails attaching the individual wax patterns to the sprues and gates, and after the trees are assembled, the sprues are coated with a dip-seal wax to fill the voids on the rough sprue surfaces.

The next step in the process is the formation of the ceramic mold. This is accomplished by dip-coating the wax trees in a ceramic slurry and a fluidized bed of silica, and air drying of the coated tree. This process is repeated several times before the wax is melted out of the mold.

Dewaxing is by one of three techniques: steam autoclave, microwave oven, or flash firing in a mold furnace. Most foundries apparently use the

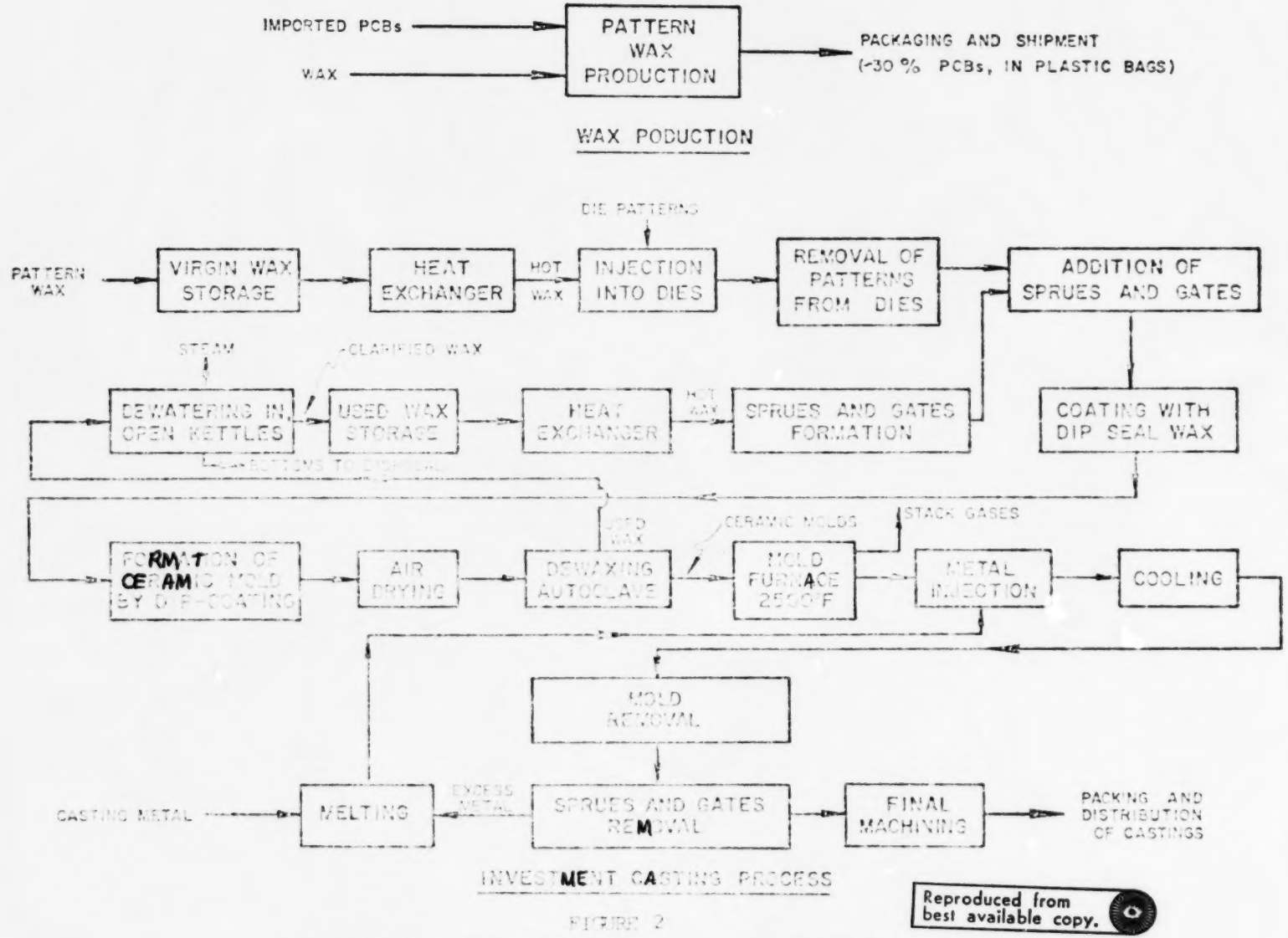

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FIGURE 2

FLOW CHART OF PCBs USAGE IN INVESTMENT CASTING

autoclave technique, which involves subjecting the ceramic coated trees to steam until the wax within the mold is melted out, leaving the ceramic shell. The melted wax is either disposed of or reclaimed for use as sprues and gate wax. The new microwave technique involves heating the molds with microwave energy. Microwave units of 5- and 10-kilowatt output are commercially available for this application. The third technique of flash firing combines dewaxing and mold firing in one step. The ceramic coated wax trees are placed in a furnace where all the wax is removed from the tree by flash firing. Most of the wax is vaporized and leaves the furnace with the stack gases. It is not known how many facilities use flash firing.

If the foundry dewaxes the trees using autoclave or microwave techniques, the dewaxed ceramic molds must be fired in the mold furnace to strengthen the ceramic and to remove wax residues. The ceramic molds are raised to temperatures of between 1900 and 2000°F for approximately two hours. The vaporized wax residues leave the furnace with the stack gases. The foundries claim that only 1 to 2 percent of the wax remains in the molds before mold firing. This estimate of trapped or wall absorbed wax appears to be low for two reasons:

(1) The porosity of the ceramic mold can be as high as 30 percent, and

(2) Trapped waxes in the cavities of the pattern vary in amount, depending on the pattern's geometric configuration.

After firing, the ceramics are ready for metal pouring. The steps involved in pouring, and the subsequent recovery of the castings are evident in Figure 2, starting with metal pouring.

The high cost of pattern wax has stimulated foundries to reclaim used wax. For example, the PCB filled waxes sell for approximately 70 cents per pound. The average weight ratio between pattern wax and wax in sprues and gates is about 40:60. Therefore, reclaiming of used wax, especially for use in sprues and gates, has become a very important part of the foundry process.

Reclaiming involves placing the used wax in open kettles or tanks and heating it above the boiling point of water until all the water (from the steam autoclave) is eliminated. After dewatering, the reclaimed wax is reconstituted by adding paraffin and other additives until certain melting-point specifications are met. It is claimed that wax fillers are not added to adjust the filler content.[4]

For those foundries who practice wax reclamation on their used wax, it is estimated that 5 to 10 percent of the wax is deliberately disposed of. The major source of the discarded wax is probably the dregs from the dewatering kettles.

4.0 OUTLINE OF STUDY PLAN

A detailed study plan of the investment casting industry is presented in outline form below. Very little of the information required has been available heretofore from the industry or other sources. Discussions of the various information areas, including data gathering methodology, sources of data, sampling and analysis requirements, are presented in succeeding sections.

4.1 Characterization of Industry Scope

4.1.1 Information from Producers, Importers, Distributors, and Wax Manufacturers (includes historical data)

(1) Quantities of PCBs and PCTs reported sold and purchased
(2) Formulation of waxes sold
(3) Amounts of wax made and sold per U. S. region
(4) Sale prices, grades, quantities, period of shipment
(5) Impurities, such as PCBs in PCTs
(6) Amounts reclaimed, if applicable
(7) Physical properties of products
(8) Cost of wax production

4.1.2 Information from Investment Casters (includes historical data)

(1) Amounts of wax purchased, used, reclaimed, and stockpiled
(2) Nature of casting products
(3) Wax use per product unit
(4) Costs per product unit

4.1.3 Other Information - General Sources

(1) Role of investment castings in user industries - technology, economics, alternatives, history, etc.

4.2 Process Characterization

4.2.1 Wax Manufacturing Process

(1) Preparation of detailed flow charts, including all process and ancillary streams and conditions
(2) Identification of known or potential waste streams plus any treatment, with approximate quantities and (if known) compositions
(3) Documentation of waste disposal methods
(4) Definition of process for reclamation of used wax

4.2.2 Investment Casting Process

(1) Upgrading of current flow chart including process conditions
(2) Detailed definition of dewaxing alternatives (steam autoclave, microwave oven, flash process), extent of use, and expected future use of each
(3) Identification and quantification of waste streams using information from industry
(4) Definition of reclamation process

4.2.3 Sampling and Analysis Recommendations

(1) Raw materials and wax products (including impurities)
(2) Used wax and solid waste streams
(3) Water effluents
(4) Air emissions (particularly exhaust from mold firing unit)

(5) Selected process streams (as necessary)

(6) Applicable reclamation process streams

4.3 Alternative Technology

4.3.1 Data Requirements for Substitute Filler

(1) Technical

- dimensional tolerance requirements
- melting/softening point
- ash/metal content
- heat transfer properties
- coefficient of thermal expansion

(2) Costs

- raw material costs
- differential costs in wax manufacture
- differential costs in investment casting
- reuse/reclamation potential

(3) Previous use history in casting processes

(4) Environmental and health effects (see Section 4.4)

4.3.2 Use of Unfilled Waxes

(1) Technical data

- dimensional tolerance effects
- heat transfer effects
- process changes

(2) Cost and economic data

- changes in operating costs per unit
- net changes in product cost
- economic impact on wax manufacturers
- cost of unfilled wax

(3) History of unfilled wax use in investment casting
- types used in the past
- types available now

4.3.3 Comparison of Filler Substitutes versus Use of Unfilled Wax

(1) Tabulation and comparison of technical and cost data
(2) Determination of list of most promising use alternatives

4.4 Environmental and Human Health Effects

4.4.1 Environmental and Toxicological Effects of Currently Used Fillers

(1) Survey of available literature on physical and chemical properties, toxicology, and biochemistry of:
- decachlorobiphenyl
- polychlorinated terphenyls
- contaminants present in deka and in PCTs
- other wax constituents

(2) Information gathering from researchers who have worked or are working with the materials of interest or with similar compounds

4.4.2 Environmental and Toxicological Properties of Potential Substitutes

(1) Review of environmental effects and toxicology literature on most promising use alternatives
(2) Comparison of environmental acceptability with current PCB and PCT fillers using available information
(3) Recommendation of experimental protocol necessary to establish environmental acceptability, if necessary

5.0 DETAILED DISCUSSION OF THE INDUSTRY STUDY PLAN

This section of the report presents details of the study plan for a thorough evaluation of the investment casting industry, including wax manufacturing.

5.1 Objectives of the Plan

Before proceeding to the details of the study plan, it is appropriate to restate the major objectives of the plan. The objectives are:

- Verification of the magnitude of the PCB and PCT use.
- Identification and quantification of PCB and PCT losses to the environment.
- Evaluation of reasonable alternatives to using PCB and PCT waxes.
- Evaluation of the potential utilization of control or abatement technology (where environmental losses do occur) and safe handling, storage, and transporting practices.
- Evaluation of the potential microeconomic impact resulting from the institution of:
  (1) alternatives to PCB and PCT waxes,
  (2) control or abatement technology, and
  (3) safe handling, storage, and transportation practices.
- Evaluation of environmental and human health effects.

5.2 Material Balance

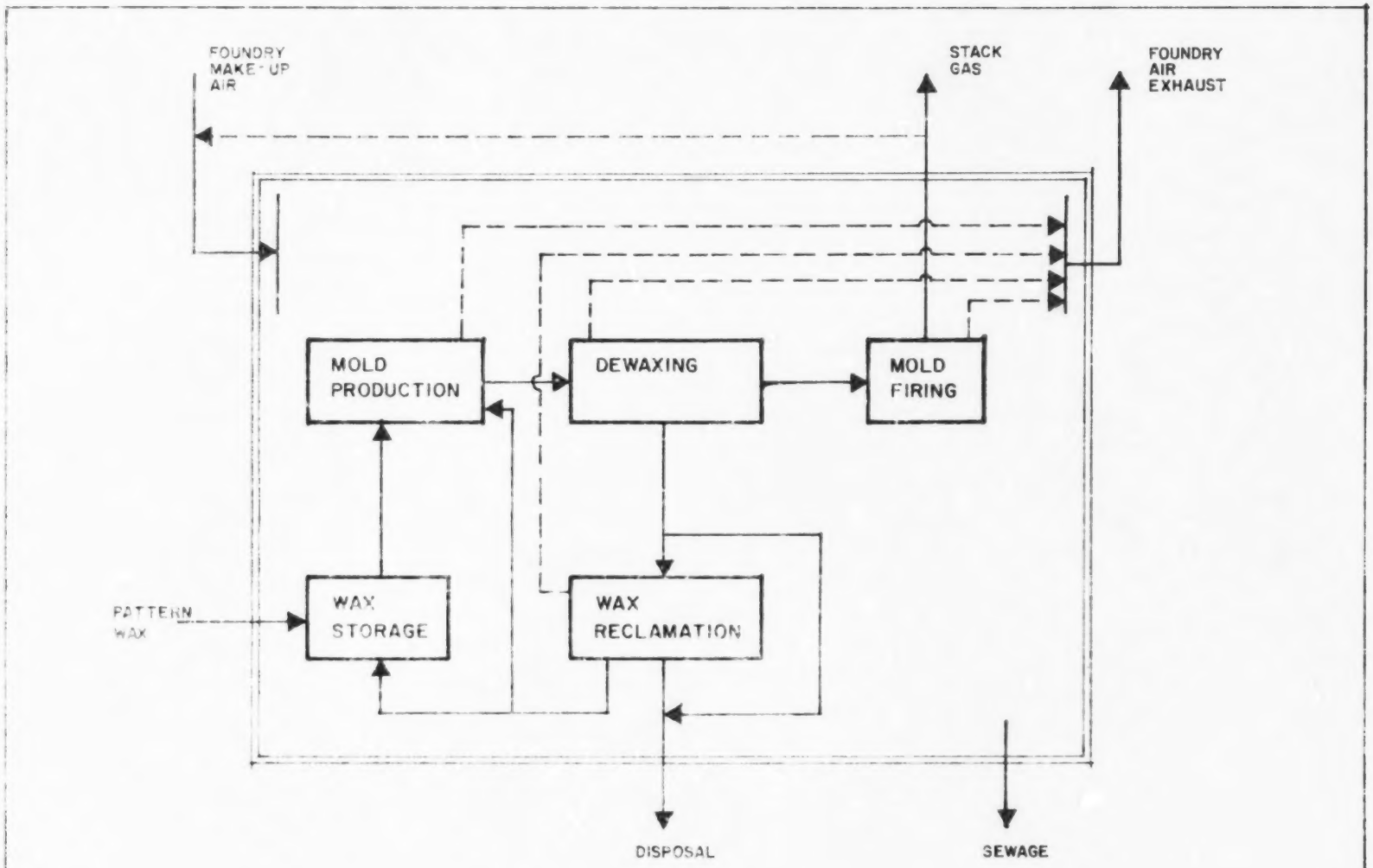
A very important aspect of the proposed plan is the development of a realistic material balance model for PCBs and PCTs in the investment casting industry. A material balance, in addition to verifying the magnitude of PCB and PCT use, would identify the loss routes and determine the amounts of PCBs and PCTs escaping to the environment from wax manufacturing and investment casting facilities.

5.2.1 Investment Casting

The first step in conducting a material balance for an investment casting foundry is to identify all streams potentially containing PCBs and PCTs. Figure 3 is a flow chart showing input and waste streams. The broken lines within the process box in Figure 3 indicate potential PCB and PCT escape routes via air emissions from the foundry unit processes. The solid lines between the processes indicate the production routes of the waxes. The solid lines at the top of the figure indicate the two general ambient air escape routes, namely the stack gas from the mold firing furnace and the foundry exhaust air system. The two solid lines leaving the foundry (at the bottom of the figure) represent PCB and PCT escape routes: solid waste, which is usually sent to landfills, and raw sewage, which goes to municipal sewage treatment in most cases. The broken line outside the facility (at the top of the figure) indicates the possibility for inadvertent recycling of escaped PCBs or PCTs in stack gas or foundry air exhaust back into the foundry facility.

As described in Section 3.0, PCB- and PCT-containing waxes enter the foundry as pattern wax packaged in plastic lined boxes which are stored until needed in the casting process. During mold production, when the wax is melted and injected into metal dies, wax fumes may escape. The type of dewaxing method employed by the foundries has a direct effect on the amount and mode of PCB or PCT loss to the environment, not only during dewaxing but also during process steps that follow. For example, the use of a steam autoclave, in addition to its own potential emission of PCBs or PCTs, also imparts moisture to the wax, and this water must be removed before the wax can be reused. Dewatering by evaporation at high temperature also likely contributes to air emissions. Flash firing, which combines mold firing and dewaxing into one step, probably emits high levels of PCBs or PCTs, and so far as is known, emission controls are not used.

Solid wastes can include unreclaimed used wax, excess reclaimed wax, bottoms from reclamations, and wastes from spills, equipment cleanout, etc.



IDEALIZED FLOW CHART FOR AN INVESTMENT CASTING FOUNDRY, SHOWING WASTE STREAMS

Although process water does not appear to be used, some plants may use cooling water. The steam autoclave appears to be a source of water vapor only.

5.2.2 Preparation

The development of a material balance will be based on information gathered during the first stages of the study, as outlined in Section 4.0. From the collected information, the investment casting foundries would be categorized by:

(1) Dewaxing process - steam autoclave, flash firing, microwave ovens, or others,
(2) Major type and status of wax used - PCB, PCT or other waxes,
(3) Weight of castings produced annually,
(4) Amount of pattern wax (and reclaimed wax) purchased annually, and
(5) Whether or not wax is reclaimed, and amount reclaimed.

Once categorized, several foundries would be selected for a comprehensive material balance. Based on conclusions formulated after categorizing the foundries, it may be found necessary to study in detail as many as six foundries in order to typify the entire industry. Table I summarizes characteristics that must be evaluated. However, this schedule could be altered by the results of the industry study; for instance, it is not known whether both PCB and PCT waxes are flash fired.

5.2.3 Sampling and Analysis Plan

The sampling and analysis plan for the performance of a mass balance at each selected foundry must utilize accepted and standardized sampling and analysis methods, and it should be performed with minimum interruption to the foundry process. Since investment casting is a batch process, it is proposed that a batch run of pattern trees (containing sprues and gates) be followed from mold production to wax reclamation and mold firing. The general approach

TABLE I

CHARACTERISTICS OF INDIVIDUAL FOUNDRIES BEING STUDIED

Types and Amounts of Pattern Wax Used

Deka-filled
PCT-filled
Other fillers
Unfilled

Dewaxing Process

Autoclave
Microwave oven
Flash firing
Other

Wax Reclamation

Amounts of wax reclaimed in comparison to the industry average

Weight of Castings

Average casting weights, compared to industry averages

would be to start a batch run with known amounts of filled pattern wax and reclaimed wax (both well characterized) and to trace the wax and its filler through the investment casting process. Of especial importance are weight measurements of:

- pattern wax and used wax in the trees prior to ceramic coating;
- ceramic coated trees (wax filled) thoroughly air dried;
- combined wax and water draining from autoclave during dewaxing;
- ceramic trees (empty molds) prior to firing.

All the melted wax draining from the dewaxer (autoclave) would be weighed and the moisture content determined. These data combined with PCB or PCT emission analysis performed on the mold furnace stack gases would quantitate the magnitude of PCB or PCT losses during mold firing. In addition, it is proposed to quantitate the foundry losses of PCBs or PCTs through the air exhaust system, the raw sewage stream, and through solid waste disposal.

The PCB or PCT content of reclaimed wax is of particular importance since this determines the PCB or PCT content of the used wax in the tree and gives an insight into the fate of the filler in the reclamation process; the bottoms from the dewatering kettles may be filler-rich, or the used wax may be filler-rich.

The protocol for conducting a sampling experiment at a foundry might resemble the following:

(1) Perform reference gas sampling in mold production, dewaxing, wax storage, wax reclamation, mold furnace areas;

(2) Perform reference gas sampling on mold furnace stack gases, foundry exhaust and foundry air return, and determine mass flow rates;

(3) Collect reference samples of cooling water (if used), intake water and raw sewage;

(4) Collect samples of pattern wax and reclaimed wax destined for use in the production of the batch run of wax trees to be followed;

(5) Perform gas sampling for PCBs or PCTs in mold production area during mold production;

(6) Collect samples of cooling water;

(7) During tree assembly, weigh each wax pattern before attaching to the sprue of the tree. The summation of the individually weighed patterns will represent the total pattern wax contained in the batch run;

(8) Weigh the assembled trees prior to coating with ceramic, since:

[weight of trees] - [weight of pattern] = [weight of reclaimed wax in batch] ;

(9) Weigh ceramic coated trees prior to placement in autoclave;

(10) Perform gas sampling for PCBs or PCTs in dewaxing area during dewaxing of the test batch of molds;

(11) During dewaxing, weigh all the melted wax (and entrained moisture) drained from the mold dewaxer;

(12) Collect a sample of the melted wax;

(13) Weigh "dewaxed" trees prior to mold firing:

[weight of ceramic coated (wax filled) trees] - [weight of dewaxed tree] = [wax residue remaining in ceramic molds] ;

(14) Perform gas sampling for PCBs or PCTs in the mold furnace area during mold firing of the test batch;

(15) During mold firing, perform stack gas sampling for PCBs and PCTs and determine the stack gas mass flowrate;

(16) Perform gas sampling for PCBs and PCTs in the foundry exhaust and return air streams and determine mass flow rates;

(17) Perform gas sampling in the wax reclamation area;

(18) Collect samples of waste wax (especially from wax reclamation areas) destined for waste disposal and samples of newly reclaimed wax.

All samples would be analyzed for PCBs or PCTs using EPA approved methods where applicable. In addition to assaying the PCB and PCT content, the moisture content of wax samples collected from the dewaxer should be determined.

Analytical methodology should include mass spectrometric verification of the presence of PCBs or PCTs in virgin wax, reclaimed wax, stack gas, facility air exhaust, cooling water and sewage stream. Once verification is established, analyses would presumably be conducted by gas chromatography versus reference standards.

5.3 Wax Manufacturing

To date, very little is known about the wax manufacturing process. However, it is known that in the process PCB or PCT compounds are added in powdered form to the wax base. Reduction of PCB or PCT particle size prior to mixing may be desired. Losses of dust to the environment by air routes from both size reduction and mixing operations would be expected.

Essential to a material balance on wax manufacturing is a thorough understanding of the wax manufacturing process. Once achieved, a material balance program could be designed to assess the environmental losses. Depending on the specific processes involved, this may or may not require a comprehensive sampling and analysis program such as is outlined for the foundry process in Section 5.2.

5.4 Summary of Results from Investment Casting Industry Study Plan

Important results from the investment casting industry study are characterizations of:

(1) Scope of the industry, including definition of materials and processes used;
(2) Product types and quantities;
(3) Technical aspects of substitutability (use history of alternatives, dimensional tolerance requirements, etc.);
(4) Use and applicability of emission controls and waste reduction from current waxes and alternatives; and
(5) Waste streams, losses, and disposal methods.

The combining of process data with the results of the sampling and analysis program will produce a definitive material balance for the casting process and will define the waste streams and losses as in (5) above. The importance of accurate loss data is illustrated by the current range of estimates from industry and other sources of 1 to 10 percent wax loss for the autoclave furnace-firing method; considering that the wax is used an average of 2.5 times, total stack losses could be as high as 25 percent of the material purchases. With flash firing, air emission losses could be even higher. The program results will also provide a comparison of the different types of dewaxing processes in terms of losses.

Recommendations to industry, on material handling, storage, and housekeeping, should also result from the study.

5.5 Role of Section 308 Authority in Study Plan

In our data gathering contacts with the investment casting industry under Tasks I and III of Contract 68-01-3259, we have received only limited cooperation. Initially, the wax manufacturers would receive telephone calls and answer some questions, but they have recently displayed some antipathy toward the efforts of Versar and EPA in gathering data on PCBs and PCTs. Nearly the reverse has been the case with the wax users (investment casting companies), who were strongly influenced by their wax suppliers until recently when some have become more open in giving information. However, this cooperation has not been industry-wide.

Thus we expect generally poor industrial cooperation in the implementation of the study plan, with the major opposition originating from the wax manufacturers. In addition, investment casting is an industry using relatively low levels of technology and having little awareness of environmental problems; the industry has been essentially unregulated and does not appear to utilize even rudimentary control procedures.

Responses to the current series of 308 inquiry letters by EPA will be extremely helpful in the final planning and implementation of the study plan. Authorization to enter plant premises and conduct sampling activities to define PCBs and PCT levels in process streams will probably be necessary to the generation of a combined process and waste material balance. It should be noted here that emissions to air from the casting plants are expected to be significant, and thus authorization for air emission monitoring would probably be essential to the study.

In summary, the current series of 308 letters on PCBs and PCTs will be most helpful to the study, but authority under Section 308 will be necessary both for more detailed characterization of the industry and its processes, and for the performing of in-plant sampling activities.

6.0 DISCUSSION OF ALTERNATIVES STUDY

At the present, there appears to be no technological barrier to cessation of the use of decachlorobiphenyl and PCTs as investment casting wax fillers, although potential effects of filler substitutes or of the use of unfilled wax on dimensional tolerances of the cast products must be evaluated.

A list of acceptable property values of casting waxes must be generated. High melting point, high thermal conductivity, low coefficient of thermal expansion, and low ash content are the necessary properties of a filler substitute. In addition, the substitute should be minimally injurious to the environment and should pose no threat to human health. Minimal economic impact resulting from increases in raw material costs is also obviously desirable.

Information on the technical and cost aspects of filler substitutes, and on the alternative use of unfilled waxes, must be obtained from industry sources since there appears to be very little literature applicable to this problem; and because the industries involved are not technically oriented, much of the information which will be available will consist of personal opinions or observations of knowledgeable figures in the casting and wax production industries.

If the hypothesis that the advantages of PCB and PCT fillers arise from physical and not specific chemical properties of the wax formulations is correct, then technically acceptable alternative formulations should be available. Of course, substitute fillers will have to be adequately demonstrated before an industry-wide changeover can occur, and the effects on industry cost structure will also have to be shown to be sufficiently small for the investment casting process to remain competitive.

Once a list of acceptable property values of fillers is available,

and is found to be generally agreeable to the wax users, the search for substitutes can be widened. At present, of course, the most promising alternatives are those which already have some use history (e.g., isophthalic acid filler[5] and unfilled formulations[6]), and the study of these would have the highest priority. Use history on other fillers would be sought from industry.

At the conclusion of the study, a complete tabulation of promising alternatives should be prepared, including use histories, physical and chemical properties, raw material costs, net changes in operating costs, estimated net effects on product costs, and environmental acceptabilities. The list would be designed for easy comparison of alternatives. Economic impact of each would be determined only in terms of a relative ranking.

The following is a brief tabulation of the potential alternatives considered to date. For comparison purposes, the decachlorobiphenyl raw material cost is about $0.50/lb and the deka-filled wax sells for about $0.70/lb.

Isophthalic acid - Amoco Chemicals Corp., Joliet, Ill.[7]

Grade	Cost in Bulk	Comments
IPA 85	$ 0.24/lb	High ash
IPA 99	$ 0.27/lb	Previous use history
IPA 110	$ 0.31/lb	Being phased out
IPA 220	$ 0.35/lb	New - low ash

Polystyrene - various producers (Dow, Monsanto, Foster-Grant, etc.)

Cost in bulk - $ 0.40/lb
Estimated additional process cost - $0.08/lb filler

New Unfilled Waxes - Freeman Mfg. Co., Cleveland, Ohio

Cost in bulk - $ 0.60 - 0.65/lb

Composition unknown

Estimated net product cost increase - 9 percent

7.0 DISCUSSION OF ENVIRONMENTAL QUALITY AND HUMAN HEALTH EFFECTS PORTION OF STUDY

7.1 Sources of Information

There is very little toxicological information available on decachlorobiphenyl and PCTs. However, the overall PCBs problem is of great general interest, and it is anticipated that useful acute and subchronic data should be available within six months. The nature of impurities in these materials needs to be defined and related to their toxicological properties.

With regard to isophthalic acid, a considerable body of literature is available on phthalic acids and phthalate esters, but their environmental fates are not known. Degradation routes, properties of degradation products, and other information needed for an assessment of environmental acceptability havenot been investigated in depth, which is probably also the case for most other filler substitutes.

It is apparent that toxicologists will be an important source of information for this phase of the study. Having knowledge of and access to toxicologists experienced with the materials of interest will be a necessary prerequisite to the collection and interpretation of available data.

The following is a tabular summary of the areas of published work to date on PCTs:

Researcher(s)	Area of Interest	Location
Allen, J. R., et al	Hepatic and gastric effects in primates	Univ. of Wisconsin Pathology Dept.
Hutzinger, O.	Environmental distribution	Nat. Res. Council of Canada, Halifax, N.S.
Kimbrough, R. D.	General toxicology of related compounds	Center for Disease Control, Atlanta, Ga.

Cecil, H. C., et al	Avian effects	USDA Animal Husbandry Lab., Beltsville, Md.
Zitko, V., et al	Distribution, aquatic effects	Research Bd. of Fisheries, Canada, St.Andrews, N.B.

7.2 Comments on Protocol for the Evaluation of Potential Substitute

Although absolute safety is the goal of society, it is never achieved. However, toxicological procedures are available to minimize risks. A standard set of protocols for safety testing that could be used in all situations does not exist. In the present case the amounts of deka and PCTs released to the general environment through investment casting activities is unknown, though emissions to air could conceivably be as high as 200,000 lbs/year, with high concentrations occurring in the vicinity of some plants.

Because of the potential for significant human exposure to substitute materials in investment casting, it seems reasonable that substitutes should undergo the same chemical and toxicological studies required of food additives. The most appropriate test procedures are those which will avoid the problems that have been encountered in the widespread use of PCBs. Certainly acute toxicity studies in at least two species by oral and dermal exposure (and, where appropriate, by inhalation) should be performed. The observation period should be at least 21 days. The material under study should also contain typical levels of the impurities likely to be encountered in a mass production situation.

Subchronic toxicity studies of a minimum of 90 days should also be performed, the purpose being to assist in the setting of dosage levels for studies of chronic toxicity. Depending upon the result of the acute dermal studies, subchronic dermal studies may also be necessary. Eye and skin irritation studies should be performed, too. Certain chemicals can be expected to produce acneform eruptions, sensitization, photosensitization, or other

irritating or corrosive effects.

The single most important test of a potential environmental contaminant, whether it be the parent compound or its degradation products, is the so-called chronic toxicity study. These studies when performed in rodents are generally carried out for at least one generation of test animals; in dogs, or other comparable species, tests last at least two years. If sufficient numbers of animals are used, the chronic toxicity study can reveal oncogenic activity. In designing chronic toxicity studies, consideration must be given to many factors, including the effects observed in the acute and subchronic studies and the estimated concentration and duration of human exposure in other instances where the compound being tested has been used; for example, occupational exposure. For the chronic studies the best test species will be that one in which the metabolism of the compound being tested most closely resembles that of man – though it is recognized that such a determination may be extremely difficult.

At present, it appears that the full set of studies outlined above has not been performed on decachlorobiphenyl or PCTs, and it is unlikely that such studies have been performed on any of the potential substitutes. For the purposes of the study outlined herein, available data should be analyzed and used to the extent possible to compare environmental suitability. One of the outputs of the study should be a detailed protocol for testing of promising substitutes in the event that insufficient information is presently available to determine environmental suitability.

8.0 REFERENCES

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4. Wurster, W. (General Manager, Consolidated Casting Corp., 2425 Carolina St., Dallas, Texas), November 5, 1975.

5. Edwards, Dan (Chicago Laboratory - Standard Oil Co., Amoco Chemical Corporation, Joliet, Ill.), Personal Communication, October, 1975.

6. Davidson, R. (Freeman Manufacturing Company, Inc., 1315 Maine Ave., Cleveland, Ohio), November 1975.

7. Connelley, J (New York Office, Standard Oil Co., Amoco Chemical Corporation, Joliet, Ill.), Personal Communication, October 1975.